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Development of UAV Research Platform for Randomized Path Planning and Control

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ABSTRACT

A small long endurance unmanned aerial vehicle (LEUAV) has been built as a research platform for randomized path planning and control. For aerodynamic modeling of the UAV, conventional vortex lattice software is used. The linear lateral and longitudinal model of the UAV is also developed. The vehicle, having 6 degrees of freedom, is capable of autonomous trajectory planning and collision avoidance in a cluttered environment. This is equivalent to search for a solution path form initial to final configuration of the vehicle in a high dimensional configuration space. Any deterministic search methods have exponential time and space complexity. Therefore, randomized methods such as Rapidly Exploring Random Tree (RRT), is used to search the configuration space with the help of a unique preprocessing scheme.

Key Words: UAV, Path Planning, Randomized Algorithms

1. INTRODUCTION

Small unmanned aerial vehicle offers a multitude of autonomous flight research applications, including autonomous formation flight, collision avoidance, sensors platform, and advanced navigation studies. Because of imperative requirement of surveillance applications in enemy territory, research on small low cost UAVs which can collect essential data in unknown or partially known environment is extremely necessary. With this view this paper describes the research and development of a Long Endurance Unmanned Aerial Vehicle (LEUAV), capable of autonomous trajectory planning in a partially known environment. The objectives of this research are a) development of a Long endurance UAV with good flying and Handling qualities, b) development a Kino-dynamic motion planning algorithm for a partially known environment and c) development of a Robust flight controller.

In general, modeling, simulating and flight testing of full scale aircraft is well documented. However, literature becomes less available when it comes to small UAVs. We used AVL and XFLR 5 [6, 7] as basic simulation software for studying and modifying the aerodynamic property of the UAV configuration. Both these software are specifically designed for simulation of low Reynolds number aerodynamics. We computed the approximate linear longitudinal and lateral model of the UAV and used this for path planning and control. In section 2 and 3 we describe the geometry and aerodynamic modeling of the UAV. In section 4 we briefly describe the path planning approach. In subsequent sections we summarize and conclude.

2. UAV Geometric Data

The UAV is primarily designed to use for surveillance purpose. It is a conventional wing-tail configuration tapered wing aircraft, having a wing span of 1.6m and a fuselage length of 1.1m. Distance of tail c.p from c.g of wing is 0.85m. The vehicle can carry 400gm payload which is essentially a pan zoom tilt camera. C.G is adjusted for a static margin of 0.411 cm. The vehicle weighs 2kg (including autopilot, GPS, battery, payload, gear, servos, and receiver). The vehicle is built with balsa wood. It is driven by electric motor capable of giving 3kg of static thrust.

3. UAV Aerodynamic Modeling

Airfoil selection is a compromise between maximum lift, weight, pitching moment and lift to drag ratios. Gaining in one automatically leads to a loss in other. More than 20 low Reynolds number sailplane airfoils were studied. Some of the prominent ones were ClarkY, Selig S-1223, S-1210, Eppler E-58, E-61, E-169, E-376, E-378, E-379 ultra-light, E-420, E-423, Leiback LNV-109, Church-Holinger CH-10sm, Wortman FX-74-Cl5-140, Gootingen GOE362 and RAF15. The airfoils were compared against each other on the basis of $C_{L\max}$,

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pitching moment, their lift to drag ratio and the lift co-efficient for a given angle of attack (5 degree). All the aero foils are simulated in XFLR 5 in Reynolds number range of 60,000 to 200,000. When simulated in a 2D aerofoil template, Aquila, E-432, E-558, E-639 have similar aerodynamic properties as Clark-Y. E-216, E-1223. E-748 has higher C_{L0} and $C_{L\max}$ than Clark-Y at the expense of higher pitching moment. E-1223 and E-748 have low L/D ratios. Sokolov has a high C_{L0} but stalls very early. S-1223, S-1210, E-423 seem best with respect to $C_{L\max}$ (~2) and Operating C_L (~1.2 @ 5 deg). But the above have very high pitching moments (~ -0.2). Clark Y has low Cm (~-0.08) but also low $C_{L\max}$. All these values would be scaled by 0.88 for a wing of aspect ratio 9. Based on the above analysis initially E378 is selected with a 12.5% thickness. Wings using such ultra-light airfoils need to be constructed in a continuous piece. But preliminary calculations showed that the weight of such a wing built by composites was too high. Finally, Eppler E216 (10% thickness) was selected as the wing airfoil. Aerodynamic Characteristics of E-216 at Re 200,000 as shown in following table,

$C_{L\max}$	1.5
C_{L0}	0.7
C_{m_0}	-0.15
L/D max	80
Stall	13 degree

The lowest wing loading requirement is posed based on stall speed. Wing loading based on stall speed of 10 m/s has been calculated. For a design weight of 2 kg and wing loading of $65N/m^2$, the area can be calculated to be $0.302m^2$. An aspect ratio of 9 was chosen based on initial design optimizations. To obtain an elliptic lift distribution, a taper of 0.4 has been rendered. Sweep back of wing leading edge is 12 degree. These give a root chord of 25 cm, a tip chord of 10 cm and a mean aerodynamic chord of 18 cm. To facilitate hand launching of the UAV and the component placement, a high wing design has been selected. The cruise CL would be around 0.8. The wing has been given a setting angle of 2 degree with respect to the fuselage. The horizontal and vertical tail areas have been calculated to be $675cm^2$ and $375cm^2$ respectively. The wings do not have any flaps. A clean wing configuration has been taken to reduce the drag. The control surfaces on the horizontal tail act as elevons. The control surface chord ratios are 30% of the tail chords. The operating point for the MAV is 15 m/s at 5 degree angle of attack. The wing has a dihedral of 8 degree.

3. Longitudinal and Lateral Model

The UAV is modeled in XFLR 5 an simulated using vortex lattice software AVL. The body axis aerodynamic force and moment derivative found as given below for longitudinal model.

	Axial velocity u	Sideslip velocity v	Normal velocity w
X force Cx	-0.258005	0.00	1.4057
Y force Cy	0.00	-0.6532	0.00
Z force Cz	-1.7428	0.00	-7.2628
X moment Cl	0.00	-0.2490	0.00
Y moment Cm	-0.3586	0.00	-4.6710
Z moment Cn	0.00	0.0432	0.00
	p	q	r
X force Cx	0.00	1.2849	0.00
Y force Cy	-0.177506	0.00	0.356742
Z force Cz	0.00	-18.3050	0.00
X moment Cl	-0.5359	0.00	0.2958
Y moment Cm	0.00	-23.1626	0.00
Z moment Cn	-0.1147	0.00	-0.1022

The control derivatives are as shown below.

	Elevator	Ailron	Rudder
X force Cx	0.001453	0.00	-0.0001
Y force Cy	0.00	-0.000439	0.00
Z force Cz	-0.006505	0.00	0.0000

X moment Cl	0.000	0.000222	0.000
Y moment Cm	-0.019661	0.00	0.0001
z moment Cn	0.00	0.000421	0.00

Based on this model the state space representation of lateral and longitudinal model of the UAV is derived for different velocity envelop in trim condition as mentioned in [1]. The UAV state space representation for a velocity of 15 m/s is taken as nominal model. Following is the state space representation of the longitudinal model.

$$A = \begin{bmatrix} -0.108 & 0.734 & -0.315 & -9.81 \\ -1.342 & -5.990 & 13.013 & 0 \\ -0.809 & -12.87 & -6.118 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, B = \begin{bmatrix} -0.010 & 0.2 \\ 0.091 & 0 \\ -10.54 & 0 \\ 0 & 0 \end{bmatrix}$$

$$\lambda \text{ (Short Period)} = -6.0532 \pm 12.9431i$$
$$\lambda \text{ (Phugoid)} = -0.0603 \pm 0.7704i$$

4. Sampling Based Path Planning

There exist many path-planning algorithms which can be applied successfully when vehicle considered as a point mass or the degrees of freedom of the vehicle motion is relatively low. With 6 degrees of freedom vehicle motion and several non-holonomic constraints, the path planning problem in high dimensional configuration space becomes exponential in time complexity as well as space complexity. Several of such problems proved in the literature as NP complete problem. One can find in [2] for a large no of reference to such problems. Therefore to break curse of dimensionality a randomized algorithm is been proposed. Lavalle and Knuffer proposed a unique randomized algorithm known as Rapidly Exploring Random tree [3], which is suitable for path planning in the high dimensional configuration space. In this method, essentially a search tree quickly explores the free sections of the configuration space and thus finds a solution if one exists. The RRT finds the solution in terms of a time parameterized control input sequences. The inevitable price to pay is the algorithm is probabilistically complete. The details of RRT algorithm can be found in [3]. We believe that restricting RRT within some segments of configuration space (which to be identified a priori) actually increases the probability of finding the solution path. The configuration space initially has to be segmented in a random way. The reachability between various segments needs to be calculated by repetitively exciting random points in the segments and exciting them with random inputs. A dynamic programming procedure then calculates the most probable segment sequence from start to end segments in order to find a solution path. Once the sequence has been found, search needs to be carried out sequentially by using RRT algorithm. Details of this procedure can be found in [4]. The results are shown in Fig [1] and Fig [2].

4. Conclusion and Future Work

A long endurance UAV is developed as a research platform for randomized path planning and control problem. Although, there are no specific standards for small autonomous UAV handling qualities, it is expected that without pilot in the loop the handling qualities surely expands, become less restrictive. A novel pre processing technique of configuration space for randomized path planning problem is developed. Present design does not consider the model uncertainty and disturbance effects on model. Therefore there exists a design possibility of probabilistic robust controller design for the vehicle.

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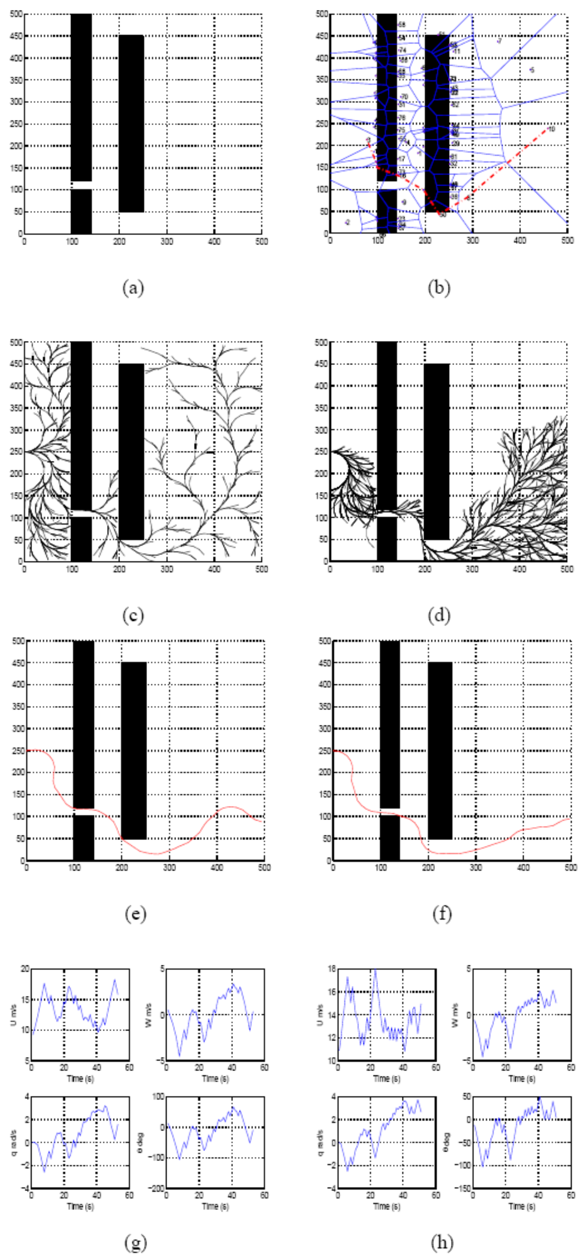

Fig. 1. (a) A hypothetical obstacle in UAV horizontal plane (b) Zone sequence as obtained from preprocessing (c) The basic RRT vertices distribution after 2000 iteration (d) Modified RRT vertices distribution after 2000 iteration (e) Path closest to the final configuration found by RRT (f) Path closest to the final configuration found by modified RRT (g) u,w,q and θ variation along the path generated by RRT (h) u,w,q and θ variation along the path generated by modified RRT.

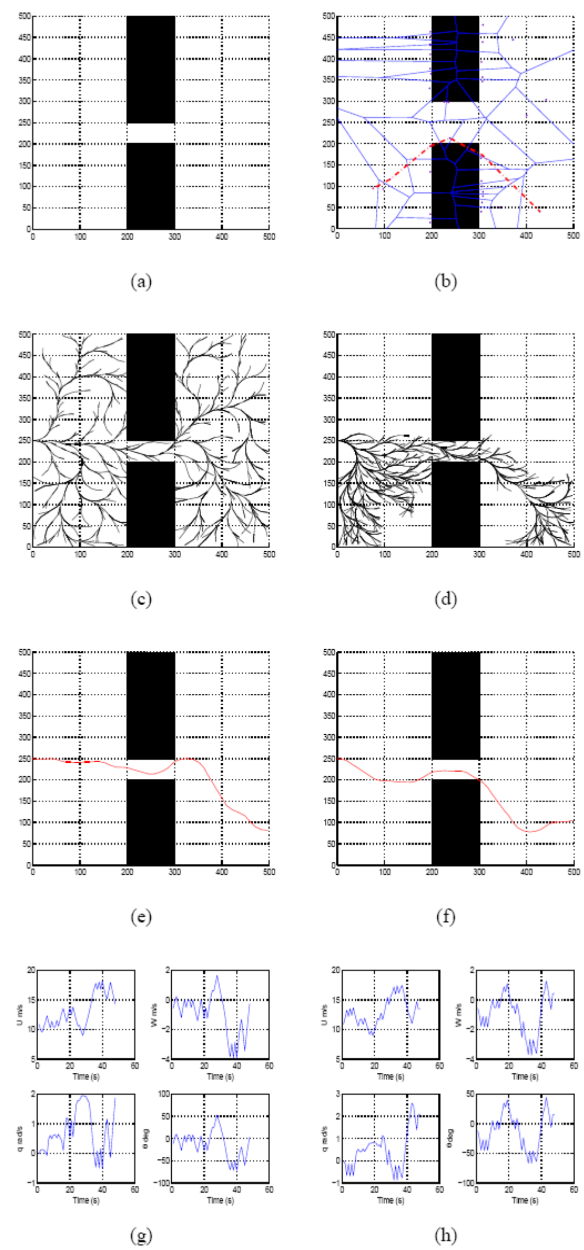

Fig. 2. (a) A hypothetical obstacle in UAV horizontal plane (b) Zone sequence as obtained from preprocessing (c) The basic RRT vertices distribution after 2000 iteration (d) Modified RRT vertices distribution after 2000 iteration (e) Path closest to the final configuration found by RRT (f) Path closest to the final configuration found by modified RRT (g) u,w,q and θ variation along the path generated by RRT (h) u,w,q and θ variation along the path generated by modified RRT.